WHITE PAPER

SUMMARY OF RESEARCH RELATED TO TRANSPORTATION OF JUVENILE ANADROMOUS SALMONIDS AROUND SNAKE AND COLUMBIA RIVER DAMS

Northwest Fisheries Science Center
National Marine Fisheries Service
2725 Montlake Blvd. E.
Seattle, Washington 98112

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CONTENTS

PREFACE

The purpose of this white paper is to provide a synthesis of scientific information regarding transportation of anadromous salmonid juveniles as it relates to the existence and current operation of the hydropower system. Other white papers are available that address the effects of predation, river flow and dam passage on salmonids. These papers are available on the Northwest Fisheries Science Center home page (www.nwfsc.noaa.gov/pubs/nwfscpubs.html).

The white papers do not address the possible effects on salmonids that might accrue from major changes to the present configuration of the hydropower system (e.g., drawdown or partial dam removal); nor do they speculate about potential indirect effects (e.g., delayed mortality) that might occur as a result of hydropower system passage. Empirical data on these subjects are scarce. Other forums, such as the Plan for Analyzing and Testing Hypotheses (PATH) and the Cumulative Risk Initiative (CRI), are addressing these issues. Nonetheless, it is recognized that many of the impacts of dams on migrant fish, as identified in the white papers, would decrease with removal of dams. Most analyses conducted to date indicate that removal of dams would lead to higher direct survival of migrant fish. Such findings are not inconsistent with anything presented in this white paper.

Following regional review beginning in October 1999, this white paper has been modified to reflect comments and information provided by numerous reviewers and resource agencies including Oregon Department of Fish and Wildlife, U.S. Fish and Wildlife Service, Idaho Department of Fish and Game, Columbia Basin Fish and Wildlife Authority, Washington Department of Fish and Wildlife, Columbia River Inter-Tribal Fish Commission, U.S. Geological Survey, Fish Passage Center, and U.S. Army Corps of Engineers.

BACKGROUND

Since the late 1960s, transportation of juvenile salmonids by truck or barge has been studied extensively by the National Marine Fisheries Service (NMFS) in the Federal Columbia River Power System (FCRPS). On the Snake River, transportation of steelhead (*Oncorhynchus mykiss*) and yearling chinook salmon (*O. tshawytscha*) was evaluated at Ice Harbor, Little Goose, and Lower Granite Dams from 1968 through 1980, and again at Lower Granite Dam in 1986 and 1989. More recently, transportation of yearling chinook salmon was evaluated using PIT-tag technology in 1995, 1996, 1998, and 1999 at Lower Granite Dam; steelhead were also PIT tagged for evaluation in 1999. On the Columbia River, transportation of steelhead and subyearling chinook salmon was evaluated at McNary Dam from 1978 through 1983, and yearling and subyearling chinook salmon were evaluated from 1986 through 1988. In addition, transportation of sockeye salmon (*O. nerka*) was studied at Priest Rapids Dam during 1984-88.

The NMFS has conducted research for more than 25 years to evaluate whether transportation of juvenile fish from upper Snake River dams increased adult returns compared to returns from juvenile fish that migrated through the hydropower system. The general methodology for all of the studies was to collect fish at a dam and mark two groups--one for transportation and one for migration through the hydropower system. Fish for transportation were placed into either trucks or barges, transported below Bonneville Dam, and released. Fish marked to evaluate migration through the hydropower system were generally trucked and released a few kilometers upstream of the dam where they were marked, or trucked downstream below Little Goose Dam and released. In the late 1970s, some control fish were released directly into the tailrace of Lower Granite Dam, but an unknown number were likely subsequently collected and transported from Little Goose Dam.

The studies were designed to compare smolt-to-adult returns (SAR) of marked smolts released in-river vs. specific groups of marked smolts transported and released below Bonneville Dam. The ratio of the SARs of transport and in-river-migrant fish were expressed as a transport-to-in-river adult return ratio (T/I). The T/I was based on results pooled from individual mark groups. For most evaluations, smolts were marked and transported from one site. Smolts that migrated in-river were released at the marking site or were transported a short distance above or below the marking site and then migrated in-river. Fish were handled and marked during most, but not all, of the outmigration period. Results were not intended to represent absolute estimates of SARs for the unmarked population.

Adult returns from nearly all studies conducted between 1968 and 1989 indicated higher SARs for transported than for in-river migrant study fish. Nonetheless, overall SARs were, in nearly all cases, much lower than SARs estimated prior to completion of the lower Snake River dams and John Day Dam on the lower Columbia River. In spite of the higher SARs of transported fish compared to in-river migrants, the ability of transportation to mitigate for dam construction and operation is controversial as absolute SARs were below historic levels.

In addition to transport evaluations based upon ratios of SARs, over roughly the last 18 years, various researchers have also evaluated and measured smolt performance, stress, mortality, disease transmission, and behavior relative to transportation.

The purpose of this white paper is to provide a summary of the scientific results of past studies of transportation. A brief description of current uncertainties is also included.

TRUCK TRANSPORTATION

Truck-transportation evaluations began at Ice Harbor Dam in 1968 and continued at various dams until the mid-1980s; however, the majority of studies were conducted during the 1970s. Studies were conducted on yearling and subyearling chinook salmon, steelhead, and sockeye salmon. No contemporary information is available on truck transportation.

Yearling Chinook Salmon

Snake River Studies

Over the course of 16 truck-transportation studies conducted at Snake River dams from 1968 through 1980, T/Is ranged between 0.7 and 18.1, with two of the studies reporting T/Is below 1.0 and two studies reporting no adult returns of either study group (Ebel et al. 1973, Slatick et al. 1975, Ebel 1980, Park 1985). In six of the studies, adults from fish transported as juveniles returned at a significantly higher rate than control fish, indicating higher survival for the transported groups. In only one study was the return rate of control fish significantly higher than transported fish. In 10 tests, adult recoveries of both test groups were too few to identify statistically significant differences between return rates of transported and control fish; however, the return rates of transported were higher than in-river-migrant study fish in most of these tests (Park 1985). Average annual total SAR estimates of marked transported fish ranged from 0.0 to 9.0% back to the Snake River dams.

Subyearling Chinook Salmon

McNary Dam Studies

Six subyearling chinook salmon truck-transport evaluations were conducted at McNary Dam from 1978 through 1983. In all studies, return rates from all recovery areas were significantly higher for fish transported as juveniles compared to in-river-migrant study fish. For fish recovered at dams, T/Is ranged from 2.3 to 10.1. Estimates of SARs back to upriver sites were not possible for these marked fish because most tags were recovered from ocean or river fisheries.

Steelhead

Snake River Studies

From 1970 through 1978, 13 separate steelhead truck-transportation studies were conducted at dams on the Snake River. In all 13 studies, steelhead that were transported as juveniles returned as adults at significantly higher rates than did those that migrated in-river, with T/Is that ranged from 1.5 to 13.5 (Ebel et al. 1973, Slatick et al. 1975, Ebel 1980, Park 1985, Matthews 1992). Average annual total SAR estimates of marked transported fish ranged from 0.4 to 4.7% back to the Snake River dams.

McNary Dam Studies

Three truck-transportation studies were conducted on steelhead at McNary Dam from 1978 through 1980. Significantly higher return rates of adults were observed from fish transported as juveniles than from groups released as in-river control fish in two of the studies. In the other study, the trucked group returned at only a slightly higher rate than the in-river control (the difference was not statistically significant). The T/Is ranged from 1.3 to 3.0 (Park et al. 1984). Estimated SARs to upriver areas for marked fish from these studies were not possible because adult recoveries were combined from several areas.

Sockeye Salmon

Priest Rapids Dam Studies

The only data available on transportation of sockeye salmon (*O. nerka*) are from studies conducted by truck from Priest Rapids Dam between 1984 and 1988 (Carlson and Matthews 1991, 1992). In 1987 and 1988, fish were trucked to McNary then transferred to a barge for the remainder of the trip to below Bonneville Dam. Final statistical analyses were not reported for these studies. The reported preliminary T/Is varied widely, ranging from 0.55 to 4.23. During these studies, no attempt was made to determine trapping efficiencies for marked adults recovered at Priest Rapids Dam. Therefore, it was not possible to estimate total average annual SARs for these study fish.

BARGE TRANSPORTATION

The initial barge-transportation evaluations were conducted at Lower Granite Dam on the Snake River from 1977 to 1980. A second round of evaluations were conducted in the mid- to late 1980s. Studies were conducted on yearling and subyearling chinook salmon (McNary Dam only) and steelhead. In 1995, a new round of evaluations began using passive integrated transponder (PIT) tags as the marking methodology. Yearling chinook salmon smolts were marked with PIT tags in 1995, 1996, 1998, and 1999 and steelhead smolts were also marked in 1999. Barge studies were also conducted at McNary Dam in the late 1970s and early 1980s.

Yearling Chinook Salmon

<u>Snake River Studies</u>

From 1977 through 1980, four barge-transportation studies were conducted on yearling chinook salmon at Lower Granite Dam. In two of the studies (1977 and 1980), no adults returned from either study group. The return rate of fish transported as juveniles was significantly higher than in-river-migrating study fish during the other two studies, with T/Is of 8.9 and 3.9 for 1978 and 1979, respectively. Average annual total SAR estimates of marked transported fish ranged from 0.002 to 0.35% back to the Snake River dams.

A second 3-year barge-transportation study on Snake River yearling chinook salmon began at Lower Granite Dam in 1986. However, no studies were conducted in the low-flow conditions in 1987 and 1988 because the fishery management agencies were primarily interested in evaluating transport in average to above average flow years as the general consensus was that transportation was superior to in-river migration during low flow years. Subsequently, only two years of the planned study were completed--1986 and 1989. Results of the 1986 research indicated a T/I of 1.6, with a 95% confidence interval (CI) between 1.01 and 2.47 (Matthews et al. 1992). Studies in 1989 indicated a T/I of 2.4, with a 95% CI between 1.4 and 4.3. Average annual total SAR estimates of marked transported fish back to the Snake River dams were 0.32% in 1986 and 0.12% in 1989.

The latest barge transportation evaluation began in 1995. In each year (except 1997), yearling chinook salmon smolts were inserted with PIT tags to evaluate transportation vs. in-river migration from Lower Granite Dam. However, unlike most previous studies, the in-river fish were released directly into the tailrace of the dam, after collection and marking. Previously applied fin clips were used to identify hatchery fish from wild fish in both the test and control groups during tagging for the study. The Lower Granite Dam study was expanded in 1999 to include steelhead smolts. From the 1995 marking, 726 hatchery and 140 wild adults were recovered at Lower Granite Dam. For hatchery fish, the overall T/I was 2.0 (95% CI of 1.7-2.1); for wild fish, the overall T/I was 2.1 (95% CI of 1.7-2.6). When compared to smolts bypassed only at Lower Granite Dam and never detected again, T/Is were 1.4 (95% CI of 0.9-1.8) for hatchery fish and 1.7 (95% CI of 1.0-2.8) for wild fish. However, overall T/Is for both hatchery and wild fish tagged in April were roughly 1.0, but increased to between roughly 2.0 and 5.0 for fish tagged in May. The main reason for this difference was that SARs of transported fish increased sharply and abruptly in early May, while SARs of in-river fish simply trended downward throughout the spring. The total combined SAR of fish marked and transported in 1995 was 0.5%, but

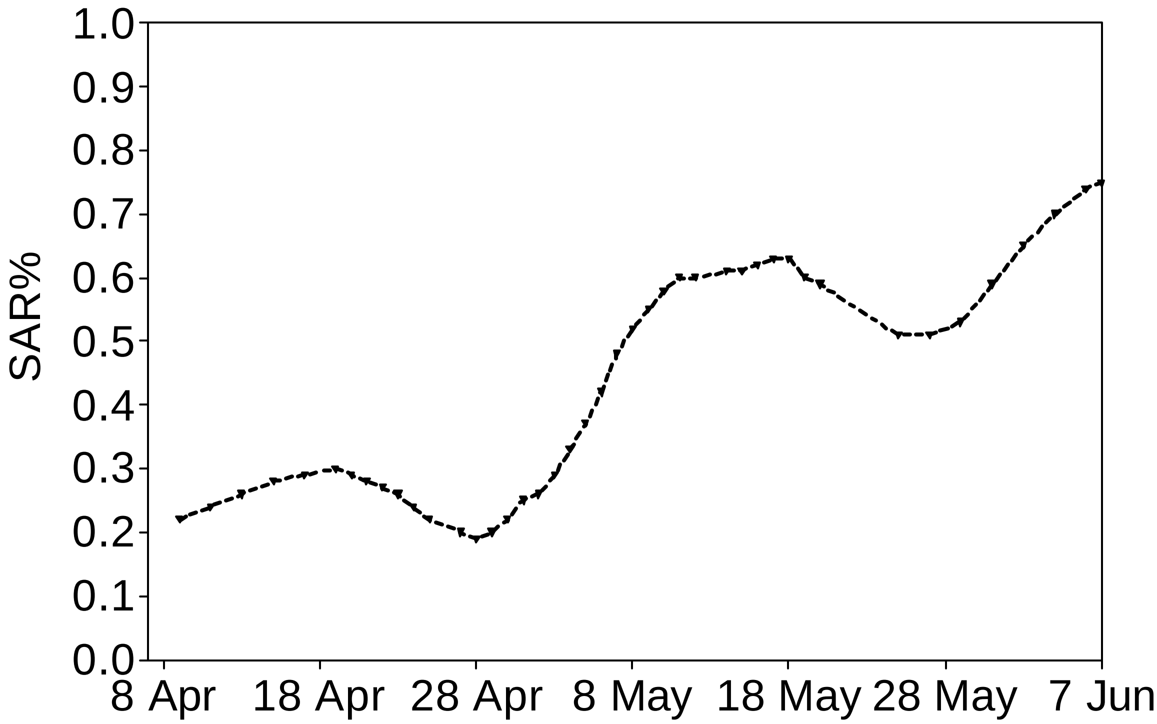

Figure 1. SARs (smoothed) of spring/summer chinook salmon smolts marked at and transported from Lower Granite Dam to a release site below Bonneville Dam, 1995.

seasonal SARs increased from roughly 0.25% prior to the first week of May to roughly 0.7% for fish transported after this time (Fig. 1).

For 1996, the respective overall T/Is for hatchery and wild fish were 1.5 (95% CI = 1.1, 2.2) and 3.4 (95% CI = 1.2, 18.3). When the SARs of transported fish were compared to those of in-river-migrant fish that were never detected again at a downstream dam after release from Lower Granite Dam, the T/Is decreased to 1.0 (95% CI 0.7, 1.5) and 1.5 (95% CI 0.6, infinity) for hatchery and wild fish, respectively.

For the 1998 study year, only jack returns are available and 61 hatchery and 6 wild jacks have been recovered at Lower Granite Dam. Initial T/Is are 1.4 for hatchery fish and 7.1 for wild fish.

McNary Dam Studies

In the late 1980s, a 3-year barge transportation study was conducted on yearling chinook salmon at McNary Dam on the lower Columbia River. Insufficient numbers of adults returned for analysis for the 1986 study year. The 1987 study showed a benefit for transportation of yearling chinook salmon, based on a pooled T/I of 1.6 (95% CI, 1.18 to 2.25). The T/Is for all individual marked groups were greater than one; however, the lower limit of the 95% CI for three of the five groups was less than one (Achord et al. 1992). Similarly, for the 1988 study, the T/I was 1.6, with a 95% CI between 1.0 and 2.6.

Subyearling Chinook Salmon

McNary Dam Studies

Barge transportation of subyearling chinook salmon was first evaluated at McNary Dam in 1983 and a subsequent 3-year study was conducted from 1986 through 1988. For the 1983 study, the return rate of fish transported as juveniles was significantly higher than in-river-migrating study fish, with a T/I of 2.9. For the three later studies, T/Is were 2.8 (95% CI of 1.4 to 5.6) for 1986, 3.5 (95% CI of 1.7 to 7.1) for 1987, and 3.3 (95% CI of 1.3 to 9.4) for 1988 (Harmon et al. 1996).

Steelhead

Snake River Studies

Barge transportation of juvenile steelhead was evaluated annually at Lower Granite Dam during the 4-year period from 1977 through 1980 and was evaluated again at the dam in 1986 and 1989. For the four earlier studies, the return rate of fish transported as juveniles was significantly higher than in-river-migrating study fish, with T/Is ranging from 1.7 to 17.5. Results from the studies conducted in 1986 and 1989 were the same as from the earlier studies. The T/Is were 2.0 (95% CI between 1.4 and 2.7) and 2.1 (95% CI between 1.3 and 3.5) for 1986 and 1989, respectively (Matthews et al. 1992, Harmon et al. 1995). For the 1977-80 studies, average annual total SAR estimates of marked transported fish ranged from 0.9 to 4.7% back to the Snake River dams. For 1986 and 1989, SAR estimates of marked transported fish were 1.3 and 0.6%, respectively.

Due to recent ESA listings of Snake River steelhead, a new series of studies to evaluate the benefits of transporting steelhead from Lower Granite Dam was initiated in 1999. The experimental design of these new studies follows the same protocols that began in 1995 for yearling chinook salmon. Final adult returns from the new steelhead studies will not be available for several years.

McNary Dam Studies

In 1979 and 1980, steelhead were marked at McNary Dam for barge transport evaluations. In both tests, the return rate of fish transported as juveniles was significantly transported than in-river-migrating control fish. T/Is were 3.0 and 1.4 for the two respective years (Park et al. 1984, Park 1985).

TRUCK VS. BARGE TRANSPORT EVALUATIONS

Barges were first evaluated and used in the Snake River transportation program in 1977, after most truck transport studies were completed. Prior to that time, all transportation studies were conducted by truck. Therefore, opportunities to directly compare truck vs. barge transportation were limited. Park (1985) reported the information in Table 1 for trucked vs. barged studies.

Table 1. T/Is for truck vs. barge transport studies for chinook salmon and steelhead as reported in Park (1985).

Year	Location	Species	Truck	Barge	**Significant?**
1978	Lower Granite Dam	yearling chinook salmon	5.8	8.9	yes
1978	Lower Granite Dam	steelhead	4.4	5.2	no
1979	McNary Dam	steelhead	2.1	3.0	no
1980	McNary Dam	steelhead	1.3	1.4	no
1983	McNary Dam	subyearling chinook salmon	3.2	2.9	no

On the Snake River, a single study comparing the two techniques was conducted with yearling chinook salmon at Lower Granite Dam in 1978. Park (1985) reported high overall T/Is for both test groups--5.8 for trucked fish and 8.9 for barged fish (99 adult returns for both transport test conditions combined); however, results differed significantly between the two treatment groups. In his report, Park appropriately concluded “This comparative test should be repeated because it was done for only 1 year, and similar comparisons with steelhead and fall chinook salmon have shown no significant benefit for barging” [over trucking]. Unfortunately, the study was never repeated (Matthews 1999). For three studies on steelhead and one on subyearling chinook salmon, there were no significant differences in adult return rates between the two treatments, although barged fish tended to return at somewhat higher rates than trucked fish. This may have resulted from differences in the release locations for the two groups. The barged fish were released 4-5 km downstream from Bonneville Dam while the trucked fish were released into the tailrace of the dam. Under present transportation procedures, nearly all fish trucked in summer are now taken by a ferry for release into mid-river downstream from Bonneville Dam. In all of the above studies, fish from both transport procedures returned at significantly higher rates compared to in-river migrants (Matthews 1999).

TRUCK TRANSPORT--CONTEMPORARY ISSUES AND APPLICATION

In a February 27, 1998 response to questions posed by the Implementation Team, the Independent Scientific Advisory Board (ISAB 1998) concluded that “Trucks should not be used in the transportation program due to a lack of information needed to advise management, due to the absence of current research programs to collect such information, and because historical indications on truck transport are negative.” However, the ISAB’s conclusion was based on evidence from studies involving truck transport directly from hatcheries or from a mid-Columbia River PUD dam (Chapman et al. 1997). Chapman et al. explicitly cautioned against extrapolating results from their studies to other other dams. No such evidence exists for truck transport from Corps of Engineer (COE) dams, although, admittedly, there are not a lot of data.

At present, in the lower Snake River, juvenile fish are transported by truck for approximately 2 weeks early in the season (late March to the second week in April), and from late June to the end of the transport season at the end of October. Transport by barge occurs in the interim. Likewise at McNary Dam, transportation (initially by trucking) begins when Hanford Reach subyearling chinook salmon predominate the daily collection and when in-river migratory conditions are deteriorating. Collection for transportation in recent years has occurred in early June. Late season trucking from McNary Dam begins about the third week of July and continues until sometime in December, when concerns related to adverse weather/driving conditions preclude collection and transportation. Fish transported by truck in the early season, however, are released from the shoreline in daylight, rather than from mid-river, as occurs in the late trucking season. Therefore, potential for predation is a valid concern.

From 1995 through 1998, 3.0, 1.9, 2.0, and 2.0%, respectively, of the yearling chinook salmon transported in the Snake River were transported by truck. Similarly, 3.1, 3.9, 6.8, and 2.5% of the wild steelhead transported were transported by truck. In contrast, 97.4, 94.0, 91.8, and 90.7% of the subyearling chinook salmon transported were transported by truck. This is because most subyearling chinook salmon migrate during summer after the COE terminates barging in the Snake River.

From 1995 through 1998 in the lower Columbia River, trucks transported 4.8, 71.3, 98.5 and 22.4%, respectively, of the yearling chinook salmon transported from McNary Dam. Similarly, trucks transported 2.5, 81.6, 91.8, and 42.7% of the wild steelhead. In contrast, trucks transported 6.3, 39.4, 64.9, and 4.1% of the subyearling chinook salmon. In the last 4 years, although the percentage of yearling migrants transported by truck from McNary Dam was sometimes high, the percentage of the total yearling migrant population transported was very low, as no fish were transported during the spring migration.

BEHAVIOR

Little research has addressed the question of whether or not transporting fish in trucks or barges causes behavioral changes in fish that subsequently reduce their fitness following release from the transport vehicle. Chinook salmon swimming performance was evaluated before and after barging, but no clear trends were observed (Schreck and Congleton 1994).

Fish behavior was examined (using underwater video) in raceways and in barges during transport. Most of the observed interactions were startle responses of undetermined cause. Classic aggressive behaviors were rarely observed. Schreck and Congleton (1994) observed the behavior of yearling chinook salmon immediately after their release from barges using radiotelemetry. They also tracked fish downstream to develop information on downstream migration speed for each radio-tagged fish and the minimum number of tagged fish that successfully migrated to the estuary. At release, most of the radio-tagged fish moved downstream at a rate of 1 to 2 miles per hour. The majority of the tagged fish reached the estuary in 36 to 72 hours after release. Radio-tagging studies indicate that run-of-river yearling hatchery chinook salmon migrate faster than do barged hatchery chinook salmon released at the same time and under the same flow conditions. Run-of-river fish also appear to travel in tighter groups than do barged fish. The authors speculate that the observed difference in travel time may result from some difference in fish condition. However, the barged chinook salmon groups were known Snake River stocks, whereas the run-of-river chinook salmon collected and tagged at Bonneville were not. The authors also speculated that an insufficient degree of smoltification, or osmoregulatory or other disturbances associated with transportation, may potentially delay ocean entry (Schreck and Davis 1997).

STRAYING/HOMING IMPAIRMENT

According to Quinn (1993), “straying is the migration of mature individuals to spawn in a stream other than the one where they originated. From the standpoint of orientation, a salmon strays if it ascends a non-natal river and does not subsequently make its way to its natal river. If a fish enters a hatchery, it is seldom given the chance to retreat, so there is some question as to whether ‘strays’ entering hatcheries would have eventually left.” Further, “estimates of straying vary greatly between hatcheries and rivers, so general statements on straying proportions have minimal biological significance.”

Natural Straying Rates

A study by Shapovalov and Taft at Scott and Waddell Creeks (California) found that steelhead strayed between the creeks at rates of 2 and 3% percent, respectively. Another study by McIsaac on the homing of wild, wild/hatchery (reared 10 weeks in a hatchery), and hatchery fall chinook in the Lewis River (Washington) found that the wild chinook strayed at a rate of 3.2%. Wild salmon have also been observed to stray into hatcheries. Nicholas and Van Dyke estimated that 64.7% of the wild coho salmon returning to the Yaquina River watershed (Oregon) in 1981 entered the Oregon Aqua-Foods hatchery (reported by Quinn 1993).

Straying Rates of Transported Snake River Fish

There is no direct evidence to show that wild and hatchery salmon, transported from Snake River dams as juveniles, stray into non-natal rivers at higher rates than would occur naturally. Reported rates of straying among transported fish are in the range of natural stray rates (1 to 3%). Marked steelhead from transport study groups (control and transported) have been reported in the Deschutes River (Oregon). Specifically, during the truck-transport studies conducted during 1970 through 1973 at Little Goose Dam, the T/Is were the same for adult steelhead recovered from the Deschutes River as for those captured at Little Goose Dam. This indicated that the trucked fish were not straying into the Deschutes River at a higher rate than did fish that migrated in-river as smolts. Further, in studies conducted between 1975 and 1980, 11 spring/summer chinook salmon (0.9% of the adult return of marked fish), and 16 steelhead adults (0.2% of the adult return of marked fish) were identified as "strays." All were transported from Lower Granite or Little Goose Dams. Among the steelhead, 11 of the 16 were released in 1976 (before barge transport began). All of the chinook salmon were observed in the Deschutes River (Oregon), whereas, the steelhead were observed at Wells Hatchery (9), the Deschutes River (3), Big Creek Hatchery (1), Chelan Hatchery (1), and the Yakima Hatchery (1). Ebel (1980) concluded, and Park (1985) agreed, that straying had a minimal impact on the overall adult returns to expected spawning areas.

In analyzing steelhead returns, Park (1985) reported that about 10% of the transported fish exhibited a consistent but small delay during their upstream migration. This delay possibly suggests that it results from an impairment in homing ability. Another possibility is that transportation changes the migration timing of fish. The proportions of transport to control adults returning over Lower Granite Dam were higher during spring than during fall, implying a delay for the transported fish. Further analysis indicated that transporting B-run steelhead originating in the Clearwater River caused a minor delay in their upstream passage (Park 1985). Matthews (1992) later postulated that the delay Park noted was more likely due to a slightly later river entry timing for adults returning from groups that were transported as juveniles. This was not observed in the A-run steelhead because most were above the dams when their migrations ceased the previous fall; therefore, they would not have been observed at the dams during the spring migration. Because B-run steelhead migrate later than the A-run, the late segment of that population would over-winter in the reservoirs below the dams and could thus be observed the following spring when they continued their migration. This may have been occurring in the A-run as well, but it simply was not observed. In any event, the slight difference in run timing, if it was real, did not appear to affect the ability of steelhead to return to the hatcheries in time to spawn successfully.

Steelhead Straying into the Deschutes River

More recently, concerns have been raised over a reported increase in steelhead reported in the Deschutes River (Oregon) that originated from a hatchery that was out of the Deschutes River basin. Deschutes River hatchery steelhead receive distinctive marks so non-native steelhead are identifiable at hatcheries and weirs. It has been suggested, based on the timing of these observations, that the majority of these fish remained to spawn in the Deschutes River. Since spawning between native and out-of-basin stocks can impact genetic viability, there is valid cause for alarm. However, observations of non-Deschutes hatchery steelhead at Sherar Falls and at upstream hatcheries have increased concurrent with decreasing proportions of steelhead transported from the Snake River. There is no direct evidence to show that the increased straying of steelhead into the Deschutes River is related to the juvenile fish transportation program.

Research that was conducted from 1992 to 1994 comparing the survival of steelhead transported to Tongue Point (in the lower Columbia River - Rkm 29.4) with that of steelhead transported to the traditional release site below Bonneville Dam (Rkm ca. 203) provides some information regarding the straying of transported fish into the Deschutes River. Overall adult returns through 1996 (preliminary results), showed that 573 steelhead returned to Lower Granite Dam and 9 were observed in the Deschutes River. This is therefore, a straying rate of 1.6%, well within expected natural straying rates. There were no marked in-river groups for comparisons in the aforementioned studies. Information from the 1986 and 1989 transportation evaluations at Lower Granite Dam showed that 1 of 500 returning adult steelhead (0.2%) was observed in the Deschutes River. Pooling all the available information from the 1986, 1989, and 1992 through 1994 studies showed that 10 of 1,073 (0.9%) transported adult steelhead strayed into the Deschutes River (Marsh et al. 1997 and unpublished NMFS data).

Straying During Priest Rapids Dam Transport Studies

Transportation of spring chinook and sockeye salmon juveniles from Wanapum and Priest Rapids Dams was researched from 1984 through 1988. These studies indicated that jaw-tagged sockeye adults (that were transported as smolts) took longer to reach Priest Rapids Dam than did the control groups in two of five years; chinook salmon adults took longer in one of three years. Jaw-tagged sockeye and chinook salmon adults from transported groups fell back below Bonneville Dam more often than did control group adults, and sockeye salmon transported solely by truck fell back more often than did sockeye salmon transported partially by barge. These results suggested that transportation impaired homing (expressed as migration delay) somewhat in adult sockeye salmon between Bonneville and Priest Rapids Dams. The studies did not, however, indicate that sockeye or chinook salmon homing was impaired between Priest Rapids Dam and spawning areas above the dam. Coded-wire tag (CWT) recoveries from sockeye salmon suggested straying occurred in four truck-transported and four control fish from the 1985 tests. Other CWT recoveries included two truck-transported and one trucked/barged sockeye salmon from the 1987 tests. The authors did not view those 11 strays as excessive—though straying likely exceeded the number estimated from other CWT records. For example, two jaw-tagged and truck-transported sockeye adults from the 1985 study were found in the Lewis River. For chinook salmon that were transported by truck, four strayed in 1984 and eight strayed in 1985. However, all of these fish had passed hatchery weirs and, therefore, could not return downstream. According to the authors, the fact that all but 1 of the 12 were from transported groups may indicate more wandering by chinook salmon trucked as juveniles. The authors cautioned that homing results observed in transported and control sockeye and chinook salmon have relevance primarily for the conditions that were created for their study on the mid-Columbia River and may or may not have relevance elsewhere for trucked or trucked/barged sockeye salmon or to other species barged from COE dams (Chapman et al. 1997).

DIRECT TRANSPORTATION MORTALITY

There are a number of reasons fish die during the collection, holding/loading, transport, and release process. Some losses are directly observable in various parts of the juvenile collection system (i.e., gatewells, wet separators, raceway screens, barge compartments, etc.). Other sources of mortality are not observable directly (e.g., impingement on screens and potential predation in raceways and during transport). Mortality following release, which may relate to the transportation experience, is not observable but may occur, for example, through increased susceptibility to predation or disease. Overall collection facility mortality has ranged from 0.1 to 8.9%, depending on the individual collection facility, the species, and life stage (COE 1997).

There are no precise data on juvenile mortality during the actual transportation process. Data from radio-tagged chinook released below Bonneville provide some information on immediate survival following release from barges. The COE estimates that average seasonal direct mortality (observable mortality before and during transport and at release) for collection and transportation combined is less than 2% (COE 1993). Stress, injury, and disease transmission are potential causes of transport-related mortality. Larger salmonids may prey upon injured, moribund, or smaller salmonids during transportation. However, observations (using video cameras) have rarely shown aggressive behavior or dead fish on the bottom of barge compartments during release. Collection facilities and operational procedures that may contribute to mortality continue to be researched.

Studies conducted from 1992 through 1996 showed no evidence of large-scale predation on smolts immediately following their release from the barges (Schreck et al. 1993a,b; 1994; 1995a,b;

1996; 1997). Using fixed and mobile radio-tracking methods, the above studies evaluated the behavior, migration speed, and migration routes taken by radio-tagged Snake River yearling chinook salmon during and after their release from transportation barges. The studies also afforded a minimum survival estimate to the lower Columbia River estuary. More recent efforts have compared the behavior of barged yearling chinook salmon with that of run-of-river yearling chinook salmon collected at Bonneville Dam. In 1996, 79 to 92% of the radio-tagged, barged yearling chinook salmon and 77 to 97% of the run-of-river yearling chinook salmon successfully reached the lower Columbia River estuary. In the 1997 studies, 74 to 97% of both groups of the radio-tagged yearling chinook salmon survived to near the estuary (Schreck and Davis 1997). The release date made no difference in the proportion of barged yearling chinook salmon reaching the estuary ($P = 0.60$, chi-square test), nor was there any statistically significant difference between the barged and run-of-river groups ($P = 0.34$, chi-square test, pooled release dates). In the 1996 tests, fish condition (as reflected by level of descaling) did not appear to affect the survival of radio-tagged yearling chinook salmon. There was no difference between individuals with greater or less than 10% descaling in either the proportion of fish reaching the estuary or in the rate of mortality within the estuary (Schreck and Davis 1997).

Data on the survival of yearling chinook salmon classified as “descaled” during marking at Lower Granite Dam are available in the NMFS 1995 transport vs. in-river migration survival study. The reported 24-hour delayed mortality of study fish was 1.6%. At the time of tagging, 4% of the juvenile chinook salmon were recorded as descaled. Twenty percent of the observed 1.6% 24-h delayed mortality were listed as descaled at tagging. Of 866 returning adults, 5% were listed as descaled at tagging. These data suggested that descaling may affect short-term survival, but may not be a factor in overall survival to adult return (NMFS unpublished data).

Mortality of intentionally descaled chinook salmon and steelhead held at the Lower Granite Dam juvenile facility did not differ significantly from mortality observed in the control groups. Of the fish that died, in both the descaled and the control groups, 75% of the chinook and 44% of the steelhead developed fungal infections prior to death. These fungal infections normally appeared on the fins rather than on the descaled areas or elsewhere on the body (Congleton et al. 1997a).

STRESS AND TRANSPORTATION

In the early 1980s, researchers began evaluating facilities used for the collection, bypass, and transport of outmigrating juvenile anadromous salmonids. The response of juvenile salmon has been assessed by measuring various physiological, performance, and behavioral traits. Studies show that collection facilities and procedures increase stress among juvenile salmonids. Much of what has been learned from this work has been directly applied to management of the juvenile fish transportation program (i.e., addition of pre-anesthesia systems, open-channel flumes, shaded raceways, enlarged barge release exits, etc.). However, nearly all of the information concerning the impacts of the transportation process on the physiology and performance of migrating smolts has been derived from experiments with hatchery fish (Schreck and Davis 1997).

Recovery From Stress

Elevated plasma cortisol levels associated with stress induced by handling and marking procedures have been found to decrease significantly (to pre-mark levels) during 3 hours of truck transportation (Matthews et al. 1987). The results of a 1993 study indicated that, even though stress indicators in juvenile salmonids were initially elevated (plasma cortisol, white blood cell levels, composition of white blood cells, diminished avoidance behavior), they decreased as the fish were barged downriver (Schreck and Congleton 1993). Studies in 1994, however, showed that the ability of yearling chinook salmon sampled from a barge at Lower Granite Dam to survive a saltwater challenge was reduced on each of three successive test dates over the course of the juvenile migration (Schreck and Congleton 1994). More recent studies (early season trials) indicated that elevated blood plasma cortisol levels (a physiological indicator of stress) in barged chinook salmon and steelhead largely returned to normal during the trip downriver. However, at the peak of the migration, plasma cortisol levels in yearling chinook salmon remained elevated throughout the collection and transportation process (Schreck et al. 1995a). Results from late season trials have been mixed.

Stress Response Differences between Hatchery and Wild Fish

Plasma cortisol concentrations taken from yearling chinook salmon in barges at Lower Granite Dam were consistently and significantly higher in wild than hatchery fish throughout the migration season. The highest cortisol concentrations in both groups occurred during peak movement of juvenile chinook salmon into the collection facility (Schreck and Congleton 1994). These data suggested that recovery from collection and loading stressors is related to loading density. Mixing species together during collection and transportation may also have been a factor.

Steelhead Stress Response

Studies in 1994 and 1995 demonstrated that collection and loading were also stressful to steelhead smolts. Recovery from stress appeared to vary widely over the course of the migration season, ranging from below, at, or above pre-collection levels. It is of interest to note that in the 1994 studies, stress indices did not decline to pre-collection levels during barge transportation to below Bonneville Dam or even to Tongue Point (an additional 20 hours of potential recovery time) (Schreck et al. 1995a).

In 1997, a laboratory experiment was conducted to determine how well steelhead tolerated a stressful event: the water level was lowered for 15 minutes at various intervals after intentionally descaling 20% of the upper body surface. The fish were sampled 16 hours after the stress event. Both descaling and exposure to low water level resulted in significant increases in enzyme levels. However, no statistically significant interactions between descaling treatment and stress exposure were found, thus suggesting that the responses to the stressor were similar for descaled and control fish at all times after descaling (Congleton et al. 1997a).

Mixed Species Stress Effects on Juvenile Chinook Salmon

Laboratory studies intended to simulate transportation practices were conducted in 1995 and 1996. Results indicated that the presence of rainbow trout (surrogate steelhead) affected the behavior and physiology of juvenile hatchery chinook salmon (Willamette River stock). Behavioral data indicated that the rainbow trout were very aggressive, while the chinook salmon were passive. In confinement, the schooling behavior of the chinook did not appear to be compatible with the territorial behavior of the rainbow trout. Physiological studies found that plasma cortisol levels were higher in chinook salmon after rainbow trout were introduced than were plasma cortisol levels in chinook salmon in control tanks (no loading) or in tanks loaded with additional chinook salmon. A second experiment found that plasma cortisol levels in chinook salmon that received inflow containing rainbow trout odor were initially similar to control group levels. However, plasma cortisol levels increased 2 hours after the odor was introduced (Kelsey 1997; Schreck et al. 1995b). These data support the need for improving fish size-separation to reduce species interactions.

DISEASE AND TRANSPORTATION

The incidence of bacterial kidney disease (BKD), the disease caused by the bacterium (*Renibacterium salmoninarum*), and the potential for its transmission between wild and hatchery stocks of yearling chinook salmon collected for transport has been investigated by the U.S. Geological Survey, Biological Resource Division (formerly the National Biological Survey). The purpose of this research was to determine if BKD contributed to poor survival of yearling chinook salmon smolts (Elliott and Pascho 1993; 1994a,b). Laboratory cohabitation and waterborne experiments indicated that the causative agent of BKD can be transmitted to healthy chinook salmon smolts during a 48-hour exposure to infected chinook salmon. Results of the 1992 studies indicated a high concentration of *R. salmoninarum* ($1x10^5$ cells per ml) may be required to infect more than 50% of the exposed fish within a 48-hour period (Elliott and Pascho 1994a).

Blood plasma samples taken from yearling chinook salmon in gatewells and barges at Lower Granite Dam, and from fish in the barges after transport, indicated that defenses against disease pathogens are significantly decreased after transportation (Schreck and Congleton 1994). In 1996, several assays were examined to determine their usefulness in evaluating the effects of stress on immune system function. Spring chinook salmon juveniles (mid-Columbia River origin stocks) were held under crowded and uncrowded conditions (0.5 lb fish/gal vs. 0.05 lb fish/gal density) and sampled at 3-, 7-, 14-, and 21-day intervals. Interferon (a factor involved in resisting viral diseases) was moderately lower than measured in the controls in one trial and was unaffected in a second trial. Oxidative burst activity by blood neutrophils (a factor involved in eliminating pathogens) was significantly depressed in the groups of crowded fish at all time periods.

From 1988 through 1992, researchers evaluated the prevalence (frequency of occurrence) and severity (degree of infection) of *R. salmoninarum* among fish in marked groups of Columbia and Snake River hatchery yearling chinook salmon, both before their release and during their seaward migration. During the study, the prevalence of infection decreased in six of the eight hatchery groups. The researchers attributed this decrease to changes in hatchery practices that reduced vertical and horizontal transmission of the infection (Maule et al. 1996).

The 1988 through 1992 studies also found that yearling chinook salmon from Snake River hatcheries had a higher prevalence of *R. salmoninarum* infections when they were sampled at dams than in the hatcheries; no similar differences were noted in comparisons of Columbia River fish. The authors thought these differences between Snake and Columbia River fish might have resulted from differing in-river conditions and the distances from the hatcheries to the dams. They assumed that after being released from a hatchery, the most severely infected fish would die first. Therefore, increases in the prevalence and severity of infection suggest that the infection progressed during the migration. The fact that increased prevalence and severity was detected in the Snake River but not in the Columbia River, suggested that the changes were caused by the river environment and not by the decreased disease resistance of fish during smoltification. The authors concluded that differences in water temperature and longer migration times caused hatchery fish migrating in the Snake River to experience higher prevalence and severity of *R. salmoninarum* than did those in the Columbia River (Maule et al. 1996).

Live-box studies suggested that, under certain conditions, uninfected salmonid smolts could become infected with *R. salmoninarum* (presumably shed from infected smolts) during in-river migration or transportation. These studies, however, did not define the levels of waterborne *R. salmoninarum* necessary for the uninfected smolts to become infected, nor did they define the probability of transmitting the disease from smolts with known infection levels to uninfected smolts (Elliott and Pascho 1995). Studies have shown that, in most years, the highest mean antigen levels were measured in fish sampled after 75% of the total migration had passed a given dam. It is of particular significance to note that when the largest numbers of fish were being collected for bypass or transportation, mean antigen levels were relatively low (Elliott et al. 1997).

The juvenile fish transportation program has established criteria that govern holding and loading operations. Specifically, collected fish may not be held longer than 2 days, and there is a maximum loading density of 0.5 lb fish/gal water. This density is normally only attained during peak spring migration periods when fish are transported by barge. Juvenile fish transport by barge from Lower Granite Dam normally takes about 35 to 40 hours, depending on weather conditions. According to Maule et al. (1996), decreasing the loading densities in raceways and ponds enhances specific immune responses of juvenile salmon. Therefore, the combination of segregating juveniles and reducing the holding and loading densities may decrease the potential to transmit of *R. salmoninarum* and enhance the ability of fish to resist the pathogen. Finally, even if BKD is transmitted from fish-to-fish, nearly all smolts arriving at the dams will have been previously infected.

Research has clearly demonstrated the high prevalence of BKD in anadromous salmonid smolts originating in the Columbia and Snake Rivers. However, whether or not transportation exacerbates mortality due to the disease is unknown.

REVIEW OF RECENT PIT-TAG DATA

Reviews of earlier NMFS transportation studies generally concluded that fish released as controls were not "true" controls because they were transported to release sites (Mundy et al. 1994, Ward et al. 1997). Thus, although transported fish returned at comparatively higher rates (i.e., T/Is > 1:1), SARs for both groups of fish were potentially lowered due to transportation to release sites. Beginning in 1997, the majority of fish arriving at Snake River dams were transported. In most years, low SARs for the population as a whole largely represented the SAR for transported fish. Many people have thus concluded that transportation was responsible for the poor performance of stocks.

Analyses of adult returns from fish PIT tagged as juveniles above Lower Granite Dam have provided new information on the efficacy of using fish marked at Lower Granite Dam for evaluations of transportation. The caveats to these analyses are that all are based on returns that have occurred in the last few years, the number of returning adults is generally quite low for any one group, and adult returns for some groups are not yet complete. Further, the number of smolts in some groups, notably those that passed through the hydropower system undetected, is unobservable and complex techniques are required to derive estimates. Because of the variability in results and generally low numbers of adult returns, it is not possible to determine if the trends identified below are significant. However, results indicate that it is important to carefully choose appropriate PIT-tagged group(s) to represent downstream migrant and transported fish in the population as a whole. For example, results suggest that SARs for fish marked at Lower Granite Dam for the recent transportation research are lower than SARs for fish in the population as a whole. Results of PIT-tag analyses are presented below.

In the first analysis, estimated SARs for smolts marked above Lower Granite Dam that were not detected as they migrated downstream through the hydropower system were compared to fish detected only at Lower Granite Dam, only at one dam (may or may not have been Lower Granite Dam), at two dams, and at three or four dams. Comparing the return rates of the fish from different groups indicates that fish detected at dams apparently had a lower return rate than fish not detected at dams (Fig. 2). While estimates of direct survival differ for fish that pass downstream through nondetection routes and those that pass through bypass systems, the differences are not sufficient to account for the apparent

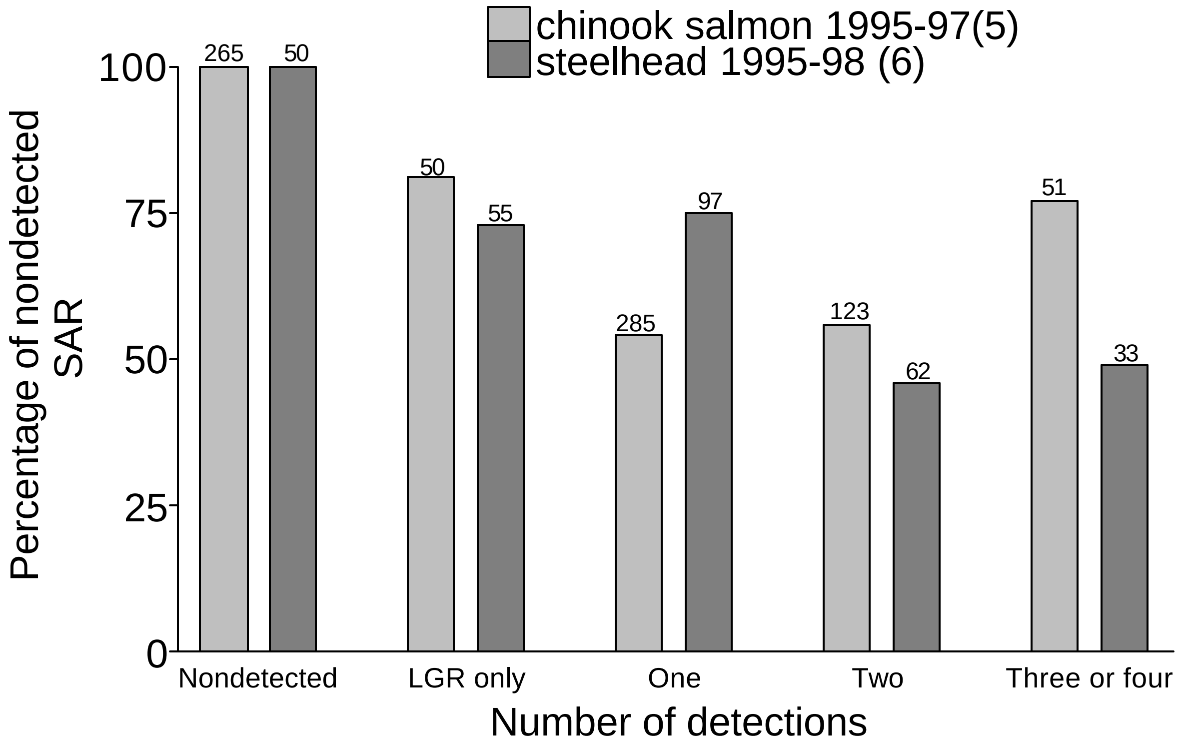

Figure 2. Ratio of adult return rates (geometric means of 5 or 6 hatchery and wild groups) of PIT-tagged fish detected at bypass systems one or more times as they passed downstream through the Snake and Columbia River hydropower system compared to PIT-tagged fish undetected as they passed downstream through turbines and spill. The total adults returns per grouping are shown at the top of the bars.

difference in estimated SARs. Among detected fish, chinook salmon show no apparent pattern in return rates versus number times detected, while steelhead appear to have lower adult return rates when detected two or more times as juveniles. Some yearly groups in these analyses are based on less than 10 adult returns. Hypotheses that might explain the potential differences in return rates are: 1) Collected fish are fundamentally weaker than non-collected fish. The poorer return rate of those fish presently collected would occur even without collection systems in place. 2) Fish collected and bypassed at dams are stressed and crowded with many other fish, which may provide conditions for disease transfer. Either increased stress or increased disease incidence leads to decreased fitness.

A second analysis compared the SAR for smolts marked above Lower Granite Dam and subsequently detected only at Lower Granite Dam to that for smolts marked at Lower Granite Dam and subsequently undetected (six comparisons - wild and hatchery spring/summer chinook salmon for 1995, 1996, and 1998). Fish marked at Lower Granite Dam returned at 53% (geometric mean of ratios ranging from 0.23 to 1.06) of the rate for fish marked above the dam (Fig. 3.), suggesting that marking at Lower Granite Dam in recent years led to decreased survival. It also suggests that SARs of fish marked at Lower Granite Dam underestimate SARs of the unmarked population of fish that arrive at the dam. Based on this analysis, the marking procedure at Lower Granite Dam will change for studies beginning in 2000.

The third analysis compared SARs for fish marked at Lower Granite Dam and transported from Lower Granite Dam to those for fish marked upstream of Lower Granite Dam and transported from Lower Granite Dam. The fish marked at Lower Granite Dam returned at 52% (geometric mean of the ratios) of the rate for fish marked above the dam (Fig. 3.), again suggesting that the marking process used at Lower Granite Dam in recent years led to decreased survival and that SARs observed for transported fish marked at Lower Granite Dam are biased low compared to the general population (unmarked) of transported fish.

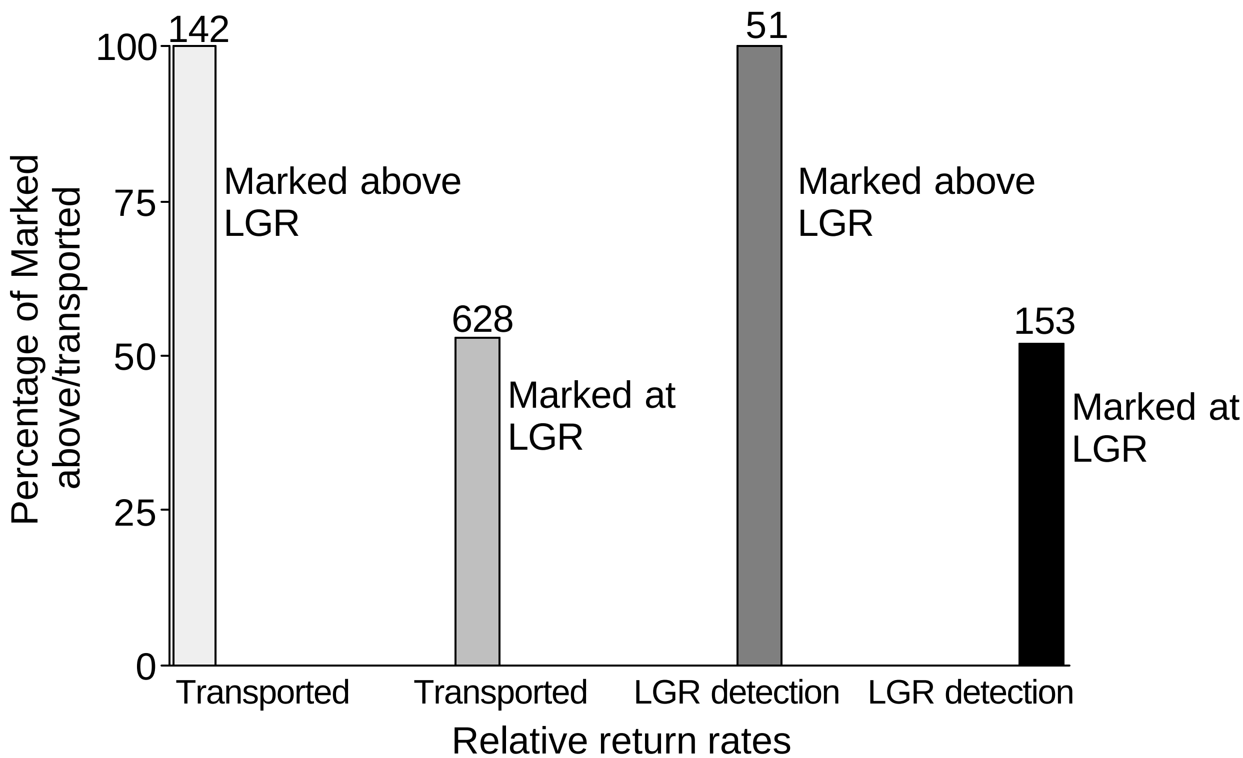

Figure 3. Relative rates of adult spring/summer chinook salmon returns (geometric means of 5 hatchery and wild annual returns from 1995, 1996, and 1998) comparing fish marked above Lower Granite Dam (LGR) to fish marked at LGR. The LGR detection fish represent fish marked above LGR and detected only at LGR and fish marked at LGR and subsequently undetected. Total adult returns per group are shown at the top of the bars.

Based on these analyses, future transportation studies will use modified procedures for handling and sorting fish before marking them at Lower Granite Dam. Further, evaluations of transportation will use fish marked and released at Lower Granite Dam, but study results will use comparisons of fish transported from Little Goose Dam compared to the estimated number of non-detected juvenile fish that pass Little Goose Dam. An analysis of return rates to date from fish marked above Lower Granite Dam provided a geometric mean of ratio of 1.33 for fish transported from Little Goose Dam compared to fish undetected in the hydropower system (for all comparisons where it was possible to estimate ratios). This compares with a 1.27 geometric mean derived from the 1995 studies of fish marked and released at Lower Granite Dam where comparisons were made of fish subsequently transported at Little Goose Dam versus fish that were not detected. Thus, fish marked at the Lower Granite Dam may not return at rates equivalent to fish marked above the dam, but the ratio of returns for the two groups should provide a reasonable comparison of transportation versus downstream migration.

Historic evaluations of transportation have compared the annual SAR of marked transported fish to the annual SAR of a comparison group that migrated downstream (aside from the fact that the majority of early studies transported “control” fish to their release sites) through the hydropower system. However, recent analyses of PIT-tagged fish show that adult return rates differ between fish with different downstream passage history (at least for detected PIT-tagged fish). Thus, PIT-tagged fish whose downstream history does not represent a possible history for untagged fish (i.e., fish that passed through bypass systems at more than one dam where untagged fish were transported) are not appropriate for transport/in-river comparisons. The PIT-tagged control group should contain only marked fish that were undetected at dams where unmarked fish were transported. From juvenile migrations in 1997 and 1998, it is expected that SARs of wild fish will meet or exceed 2%. This may provide sufficient adult returns to provide a higher level of confidence about the differences in return rates of transported to non-detected fish.

From juvenile wild spring/summer chinook salmon tagged at Lower Granite Dam for the transportation study in 1995, sufficient adults returned to detect a within-season temporal trend in SAR. In 1995, a constant proportion of spring/summer chinook salmon juveniles that arrived daily at Lower Granite Dam were PIT tagged from 8 April to 1 July 1995 (data were truncated after early June for this analysis, as sample sizes were small and no marked adults returned.) Following tagging, fish randomly assigned to transportation were held for 24-h and then loaded into barges for a 36-h trip to a release site below Bonneville Dam. Based on results from other studies, fish presumably migrated to the ocean in 3-4 days after release from the barges. The temporal pattern in adult return rates from the transported fish is striking. Fish that arrived in the estuary/early ocean after the first week of May had adult return rates that were 3 to 4 times greater than fish that arrived prior to that time (Fig. 1). Only twenty-three percent of the juveniles were released after 4 May, but they provided 39% of the adult returns. These results were not likely a function of the mechanical process involved in transporting fish, as transportation methodologies were unchanged throughout the season. These results indicate that, at least in some years, use of a single annual SAR estimate may mask considerable variability in the data.

THE BENEFITS OF TRANSPORTATION: THE "*D*" CONCEPT

The current configuration of juvenile bypass systems at dams on the lower Snake and Columbia Rivers provides the option of transporting spring/summer chinook salmon and steelhead from three locations on the Snake River (Lower Granite, Little Goose, and Lower Monumental Dams) and from McNary Dam on the Columbia River. In most recent years, the general (non PIT-tagged) downstream migrant population collected during the spring was transported from Snake River dams, but transportation was discontinued from McNary Dam after the 1994 outmigration. For fish collected at a dam, transportation is generally the preferred option when the expected adult return rate of fish transported to below Bonneville Dam exceeds the expected return rate of fish that remained in the river to migrate downstream through the hydropower system.

For a given dam, the smolt-to-adult return rates (SARs) for transported and in-river fish are each composed of two components: the survival from the collection dam to below Bonneville Dam, and the survival from below Bonneville Dam to adult return, referred to as "post-Bonneville Dam" survival. The SARs can be described by the equations

$$SAR_T = S_{d,T} \cdot S_{pb,T}$$

and

$$SAR_I = S_{d,I} \cdot S_{pb,I}$$

where the subscripts T and I refer to transported and in-river fish, respectively; S_d is downstream survival, and S_{pb} is the post-Bonneville survival. One reason to split the SARs into two components is that S_d (downstream survival) can be estimated and S_{pb} currently cannot be estimated directly but must be inferred from SARs and downstream survival estimates.

By comparing post-Bonneville survival of transported to in-river fish, we can address the question of whether transported fish survive as well after they are released as do their in-river counterparts. "Differential post-Bonneville Dam survival" has been termed "*D*" and is expressed by the following equation

$$D = \frac{S_{pb,T}}{S_{pb,I}}.$$

If transported fish and in-river fish have the same survival from the transport release site to return as adults, then $D = 1.0$. If transported fish incur greater mortality after release from the barge, then $D < 1.0$.

Based on the equations above, the familiar *T:I* ratio (ratio of the SARs) can be expressed as

$$T{:}I = \frac{SAR_T}{SAR_I} = \frac{S_{d,T}}{S_{d,I}} \cdot \frac{S_{pb,T}}{S_{pb,I}} = \frac{S_{d,T}}{S_{d,I}} \cdot D$$

Transportation benefits fish stocks from a particular location only if the SAR for transported fish exceeds that for in-river fish; that is, if the *T:I* ratio exceeds 1.0. Because $S_{d,T}$ (survival in the barge from the collection dam to below Bonneville Dam) is near 1.0, the decision essentially reduces to a comparison of survival to below Bonneville for fish that migrate in the river versus differential post-Bonneville Dam survival. In terms of the equations, transportation benefits fish only if $D > S_{d,I}$.

One consequence of this relationship is that if *D* is the same for each transportation site, then the benefit of transportation is greater for collection sites farther upstream. This is because $S_{d,I}$ increases for sites farther downstream. This follows from the common-sense deduction that fish transported from Lower Granite Dam avoid more direct in-river mortality than fish transported from McNary Dam.

Estimates of *D* for Snake River ESUs

Below we present estimates of *D* for Snake River spring/summer chinook salmon and steelhead derived from PIT-tag data. A discussion of *D* estimation for Snake River subyearling fall chinook salmon is also included.

For spring/summer chinook salmon and steelhead, annual estimates of *D* were based on T:I ratios for wild fish PIT tagged above Lower Granite Dam. The in-river control group for a given year was composed of fish that represented the unmarked population (it did not include PIT-tagged fish bypassed back to the river at dams where the general migrant population was transported). Thus, the control group was composed only of non-detected fish at Snake River dams and at McNary Dam in 1994, and of non-detected plus fish detected only at McNary Dam in 1995 through 1997. In the transport group, SARs for fish transported from different dams were weighted proportionally to the estimated proportion of non-tagged fish transported from each dam, so that transported PIT-tagged fish were representative of the transported non-tagged population at large. Estimates of *D* also depended on estimates of reach-specific survival between Lower Granite Dam and Bonneville Dam (Muir et al. *in review*, Sandford and Smith *in review*, and Williams et al. *submitted*), survival from barge-loading to below Bonneville Dam for transported fish (assumed 0.98 for all dams in all years), and on estimates of detection probabilities at collector dams. Detections of PIT-tagged fish were used to estimate survival between the tailraces of Lower Granite and McNary Dams in all years. Estimates of survival between the tailraces of McNary and Bonneville Dams were extrapolated from estimates of survival between Lower Granite Dam and McNary Dam for years when direct survival estimates were not available. Two extrapolation methods were used: 1) per-project survival between McNary and Bonneville Dams (3 projects) was assumed equal to per-project survival between Lower Granite to McNary Dams (4

projects), and 2) per-kilometer survival between McNary and Bonneville Dams (236 km) was assumed equal to per-kilometer survival between
Lower Granite to McNary Dams (225 km). Empirical survival estimates between McNary and Bonneville Dams were possible for steelhead from 1997 to 1999 and for spring/summer chinook salmon in 1999. Comparison of extrapolation methods to empirical estimates was inconclusive: per-kilometer extrapolation was closer to the empirical estimate in 3 of 4 cases, and per-project extrapolation was closer once.

For PIT-tagged wild fish of the two species, Tables 2 and 4 (based on per-project extrapolations for the lower river) and Tables 3 and 5 (based on per-kilometer extrapolations for the lower river) provide estimated SARs for transport and control groups, in-river survival estimates, and estimates of *D* with confidence intervals for each year. In addition, the geometric mean of the annual point estimates of *D* was calculated across years. All estimated SARs represent the proportion of smolts that left Lower Granite Dam that returned to Lower Granite Dam as adults.

The estimates of *D* are derived from estimated numbers of smolts in various passage history categories from analyses by Sandford and Smith (*in review*). Based on peer review of the first submitted draft of that manuscript, refinement of estimation methods is currently taking place. Slightly different estimates of *D*, based on previous versions of Sandford and Smith have been distributed elsewhere (e.g. Draft Anadromous Fish Appendix, USACE 1999). Methods for combining passage history categories to represent the population at large have also been refined since the first estimates of *D* were calculated. Furthermore, all the methods are subject to further revision, though only small effects on *D* estimates are expected. In general, estimates of D have varied little relative to the precision (width of confidence intervals) of the estimates. For example, in all iterations, the geometric mean of 1994-1996 estimates for wild spring/summer chinook salmon was between 0.78 (Table 2) and 0.83.

Table 2. Estimates of *D* for wild Snake River spring/summer chinook salmon. SAR_T is the estimated SAR for transported fish. SAR_I is the estimated SAR for in-river (control) fish. Total adult returns ( ) are provided for all estimated SARs. Surv. is the estimated survival from Lower Granite Dam to Bonneville Dam for in-river fish (per-project extrapolation). *D* is estimated for each year (along with approximate 95% confidence intervals**)**, and the geometric mean of the yearly *D* is provided. (1997 returns incomplete).

year	SAR_T (adults)	SAR_I (adults)	Surv.	*D* (95% C.I.)
1994	0.52 (13)	0.25 (6)	0.335	0.85 (0.01, 1.69)
1995	0.30 (8)	0.33 (10)	0.557	0.55 (0.03, 1.06)
1996	0.52 (2)	0.24 (5)	0.469	1.02 (-0 .69, 2.72)
1997	2.46 (4)	2.05 (17)	0.474	0.61 (-0.08, 1.29)
		geometric mean 94-97:		**0.73**

Table 3. Estimates of *D* for wild Snake River steelhead. SAR_T is the estimated SAR for transported fish. SAR_I is the estimated SAR for in-river (control) fish. Total adult returns ( ) are provided for all SARs. Surv. is the estimated survival from Lower Granite Dam to Bonneville Dam for in-river fish (per-project extrapolation). *D* is estimated for each year (along with approximate 95% confidence intervals), and the geometric mean of the yearly *D* is provided.

year	SAR_T (adults)	SAR_I (adults)	Surv.	*D* (95% C.I.)
1994	1.29 (8)	1.16 (6)	0.416	0.51 (-0.04, 1.06)
1995	0.40 (1)	0.00 (0)	0.583	NA
1996	0.59(1)	0.58 (4)	0.531	0.54 (-0.68, 1.76)
1997	0.82 (3)	0.57 (3)	0.474	0.71 (-0.45, 1.87)
		geometric mean 94, 95, 97:		**0.58**

Table 4. Estimates of *D* for wild Snake River spring/summer chinook salmon. SAR_T is the estimated SAR for transported fish. SAR_I is the estimated SAR for in-river (control) fish. Total adult returns ( ) are provided for all SARs. Surv. is the estimated survival from Lower Granite Dam to Bonneville Dam for in-river fish (per-kilometer expansion). *D* is estimated for each year (along with approximate 95% confidence intervals**)**, and the geometric mean of the yearly *D* is provided. (1997 returns incomplete)

year	SAR_T (adults)	SAR_I (adults)	Surv.	*D* (95% C.I.)
1994	0.52 (13)	0.25 (6)	0.260	0.66 (0.01, 1.31)
1995	0.30 (8)	0.33 (10)	0.501	0.49 (0.02, 0.96)
1996	0.52 (2)	0.24 (5)	0.412	0.89 (-0 .60, 2.39)
1997	2.46 (4)	2.05 (17)	0.417	0.54 (-0.07, 1.14)
		geometric mean 94-97:		**0.63**

Table 5. Estimates of *D* for wild Snake River steelhead. SAR_T is the estimated SAR for transported fish. SAR_I is the estimated SAR for in-river (control) fish. Total adult returns ( ) are provided for all SARs. Surv. is the estimated survival from Lower Granite Dam to Bonneville Dam for in-river fish (per-kilometer expansion). *D* is estimated for each year (along with approximate 95% confidence intervals), and the geometric mean of the yearly *D* is provided.

year	SAR_T (adults)	SAR_I (adults)	Surv.	*D* (95% C.I.)
1994	1.29 (8)	1.16 (6)	0.336	0.41 (-0.04, 0.86)
1995	0.40 (1)	0.00 (0)	0.528	NA
1996	0.59(1)	0.58 (4)	0.476	0.49 (-0.61, 1.58)
1997	0.82 (3)	0.57 (3)	0.474	0.71 (-0.45, 1.87)
		geometric mean 94, 95, 97:		**0.52**

Adult returns of wild Snake River salmonids PIT tagged above Lower Granite Dam were particularly small, yielding large confidence intervals about the yearly estimates. Thus, the above *D* estimates should be viewed with caution. Much more data will be necessary before more reliable and more meaningful *D* estimates can be calculated.

It is not surprising that survival of transported fish in the post-Bonneville phase is generally not as high as that of in-river fish. First, passage through reservoirs and dams likely culls weaker downstream migrants, with only the stronger fish surviving to below Bonneville Dam. Transported fish face no physical obstacles and are generally released below Bonneville Dam within 36 to 48 hours after collection. The culling process for them likely continues after release. Moreover, some fish arriving at the hydropower system are certain to die (i.e., fish with active or advanced bacterial kidney disease infections) during the ensuing 3-week period whether they migrate through the hydropower system or are transported. These fish would die even if the hydropower system were not in place. Survival estimates of in-river fish account for this mortality. If transported, these fish would not die until after release below Bonneville Dam. Finally, high fish densities on barges may cause stress and promote horizontal disease transmission, either of which could result in greater mortality after release than the in-river migrants.

For Snake River fall chinook salmon, a great deal of uncertainty exists regarding the value of *D*. This is primarily because no formal transportation studies have been performed for these fish, and thus the empirical basis for *D* estimates is not as strong as for spring migrants. Estimates of *D* require multiple assumptions, which are usually model-based. In addition, transportation methods have changed through the years, from fish being released near the bank of the river in areas known to have concentrations of predators (1993 and before) to being released in the middle of the river at varying locations (1994 and after). Further, transportation modes may change in the future from primarily trucked-based to more reliance on barges (there is concern that trucked fish don't have the opportunity for imprinting and may be prone to straying).

The PATH analysis of Snake River fall chinook salmon (Peters et al. 1999) used several methods to estimate *D*, each with inherent strengths and weaknesses. The first method was to estimate *D* from spawner-recruit data by incorporating *D* as a "free" parameter in a life-cycle model. This resulted in a wide range of values with a median value of about 0.05. However, the estimate of *D* is confounded with other parameter estimates, notably *E*, the spawning effectiveness of hatchery strays. The second method involved estimating *D* based on PIT-tagged fish (primarily hatchery origin), some of which were known to have been transported. For migration year 1995, this resulted in a *D* estimate of approximately 0.24. This estimate represented only one year (although the method could be used to estimate *D* for 1996), and because sample sizes were small the estimate had a large confidence interval. A third source of information is transportation studies conducted on subyearling chinook salmon (primarily Hanford Reach fish) at McNary Dam during the years 1978-1983. T/Cs for these studies were relatively large, and resulting *D* estimates were generally greater than 1.0. These results were obtained primarily from a different stock than Snake River fall chinook salmon, using different transportation operations. However, they may represent higher *D* values that possibly could be achieved with improved transportation operations in the future. Hopefully, transportation studies will be initiated during the 2000 outmigration to improve our understanding of *D* for Snake River fall chinook salmon.

KEY UNCERTAINTIES

In 1994, the Independent Peer Review Team (IPRT) completed a review of the data available on the benefits of transporting juvenile fish (Mundy et al. 1994). The IPRT findings and conclusions indicated that "the kinds of Snake River salmon for which transportation is likely to improve relative survival to the point of transportation are the steelhead, and to a lesser degree, the yearling-migrant stream-type chinook salmon designated as "spring/summer chinook" salmon by NMFS."

Although transportation research has been ongoing for a long period, uncertainties remain. Only recently has technology advanced to the point where accurate and precise information can be gathered.

Some people have concluded that control groups of fish from the past transportation studies did not represent the run-at-large, since these fish were collected and marked after passing through a juvenile bypass system. The effects and potential bias of this "handling" is the subject of continued debate.

To address some concerns with past study designs will require marking of transportation study fish prior to arrival at dams where evaluations are to occur, as was first proposed by NMFS scientists in the early 1990s. At present, this is only occurring with hatchery fish. Ideally, evaluations of wild fish should rely on fish marked in natal areas upstream from the dams so that their origins are known, which would provide the possibility to evaluate adult homing to individual natal streams. Until wild stock abundance increases considerably, these types of studies are not possible.

Recently initiated PIT-tag studies are beginning to demonstrate the tremendous within- and between-year and, most likely, decadal variability inherent in the adult return rates of anadromous salmonids. This variability reflects the tremendous life-history variation among salmon stocks and the environments within which they exist. Sufficient long-term data sets that are based on PIT-tagged fish and that provide conclusive evidence about SARs of transported fish versus downstream migrants do not yet exist. To provide sufficient data will require marking of fish for several more years and complete adult returns will not become available for another decade. The studies will need to evaluate wild stocks independently whenever possible, as results derived from hatchery fish may not represent wild stocks. The ISAB recommended evaluation of wild fish by individual stream or stock. These evaluations are not now possible, given the low population abundances and low adult return rates in recent years. However, individual stock evaluations may be possible in the future if stocks rebound from current low levels, and/or return rates increase.

There is uncertainty regarding the levels and potential causes of post-transport and post-bypass differential mortality. For detailed discussions of post-transport differential delayed mortality, the reader is directed to the State, Tribal, and U.S. Fish and Wildlife Service response (Bouwes et al. 1999) to the Draft Anadromous Fish Appendix and Section 4.4.3.1 and Annex C of Appendix A--Anadromous Fish of the Draft Lower Snake River Juvenile Salmon Migration Feasibility Report/Environmental Impact Statement (USACE 1999). Evaluations of post-transport and post-bypass delayed mortality should receive high priority.

Based upon previous data generated from studies conducted at COE dams, the most that can be said regarding homing of returning adults that were transported as juveniles is that transport does not appear to result in a large amount of homing impairment. Research to accurately and precisely characterize the effects of transportation as juveniles on the homing characteristics of returning adults should be conducted. Installation of adult PIT-tag detectors at mainstem dams will be critical for this work.

Some people hypothesize that the transportation process exacerbates disease transmission and/or increases the susceptibility of individuals to mortality from disease or stress. However, empirical evidence to support the speculation is lacking. Studies that would increase knowledge in this area are needed.

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